



Preparation, characterization, engine combustion and emission characteristics of rapeseed oil based hybrid fuels



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ABSTRACT

In this study, hybrid fuels consisting of rapeseed oil/diesel blend, 1% aqueous ethanol and a surfactant (oleic acid/1-butanol mixture) were prepared and tested as a fuel in a direct injection (DI) diesel engine. The main fuel properties such as the density, viscosity and lower heating value (LHV) of these fuels were measured, and the engine performance, combustion and exhaust emissions were investigated and compared with that of diesel fuel. The experimental results showed that the viscosity and density of the hybrid fuels were decreased and close to that of diesel fuel with the increase of ethanol volume fraction up to 30%. The start of combustion was later than that of diesel fuel and the peak cylinder pressure, peak pressure rise rate and peak heat release rate were higher than those of diesel fuel. The brake specific fuel consumption (BSFC) of hybrid fuels was increased with the volume fraction of ethanol and higher than that of diesel. The brake specific energy consumption (BSEC) was almost identical for all test fuels. The smoke emissions were lower than those for diesel fuel at high engine loads, the NO_x emissions were almost similar to those of diesel fuel, but CO and HC emissions were higher, especially at low engine loads.

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1. Introduction

The depletion of petroleum energy resources as well as their inherent environmental concerns has led to the pursuit of renewable biofuels. Vegetable oils are being considered as such an alternative fuel because of their renewable and non-toxic nature. Researchers have evaluated the use of sunflower, safflower, soybean, cottonseed, rapeseed and orange oils as potential renewable fuel sources [1–6].

The injection, atomization and combustion characteristics of vegetable oils in diesel engines are significantly different from those of diesel fuel. The direct use of vegetable oils is generally considered to be unsatisfactory and impractical for diesel engines. The high viscosity of vegetable oil interferes with the injection process and leads to poor fuel atomization. The inefficient mixing of fuel with air contributes to incomplete combustion. The high flash point, oxidative and thermal polymerization lead to more deposit

formation, carbonization of injector tips, ring sticking, lubrication oil dilution and degradation. The combination of high viscosity and low volatility of vegetable oils causes poor cold engine start up, misfire and ignition delay period. It is therefore unsuitable to use straight vegetable oils in diesel engines [7–10].

To overcome these problems caused by the high viscosity of vegetable oils, a number of techniques have been used. These include vegetable oil/diesel blends, increasing the vegetable oil temperature, pyrolysis, vegetable oil transesterification to fatty alkyl esters or biodiesel, and vegetable oil-based micro-emulsions to make the hybrid fuel [11–16]. Attaphong et al. [17] produced a kind of vegetable oil based micro-emulsions as an alternative method of reducing viscosity and evaluated the phase behavior of carboxylate-based extended surfactant micro-emulsion systems with the goal of formulating optimized systems for biofuel. The results indicated that carboxylate-based extended surfactants were able to form micro-emulsions, thereby eliminating the phase separation and precipitation. In addition, fuel properties such as viscosity and temperature dependence were favorable and thus supported the development of these surfactant-based fuel systems for use in diesel engines. Frank et al. [18] evaluated the effects of croton oil-butanol-diesel blends on the performance and emissions of diesel engine. It was observed that BSEC of blends was found to

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Nomenclature

BMEP	brake mean effective pressure
BSEC	brake specific energy consumption
BSFC	brake specific fuel consumption
CO	carbon monoxide
CO ₂	carbon dioxides
COV	coefficient of variance
DI	direct injection
HC	hydrocarbon
K	coefficient of light absorption of the smoke
LHV	lower heating value
NO _x	nitrogen oxide
PM	particulate matter
TDC	top dead center

be higher when compared with that of diesel fuel. Butanol containing blends showed higher peak cylinder pressure and heat release rate comparable to that of diesel fuel on higher engine loads. Carbon dioxide (CO₂) and smoke emissions of the blends were lower in comparison to diesel fuel. Qi et al. [19] used oleic acid as emulsifier to produce biodiesel/diesel-methanol micro-emulsions and evaluated the performance and combustion characteristics. The results indicated that the power and torque outputs of micro-emulsions were slightly lower than those of diesel fuel. The smoke and CO emissions were evidently decreased, and NO_x and HC emissions were almost similar to those of diesel fuel. Lei et al. [20] produced a novel mixed emulsifier based on biofuel and castor oil, and studied the effects of the ethanol-diesel blends with the emulsifier on the performance and emission characteristics of a diesel engine. The results indicated that the ethanol-diesel blend can keep its physical stability at a wide range of temperatures with the emulsifier. The smoke emission was reduced significantly and the NO_x emission decreased slightly, while the HC emission increased. Singh et al. [21] produced one kind of hybrid fuel consisting of coconut oil, aqueous ethanol and a surfactant, and investigated the fuel properties, engine performance and exhaust emissions. The experimental results showed that the effective thermal efficiency of the hybrid fuels was comparable to that of diesel. The exhaust emissions were lower than those for diesel, except CO emissions. Kumar et al. [22] studied the micro-emulsion of linseed oil and mahua oil with neat diesel fuel and alcohol in varying proportion, evaluated their properties, performance and emission characteristics in a diesel engine, and concluded that the micro-emulsion of vegetable oil can partially substitute the diesel fuel with no difficulty.

Some literature revealed that vegetable oil had the environmentally advantageous and more energy efficient than corresponding biodiesel. Esteban et al. [23] concluded that Spanish rapeseed oil showed the environmental benefits instead of biodiesel by using life-cycle assessment. The energy return on investment index indicated a more energy efficient for rapeseed oil as compared to biodiesel due to the production of biodiesel which required more complex processes. Therefore, rapeseed oil was a useful option as a produced biofuel that additionally closed the cycles of all generated co-products. Hossain et al. [24] indicated that raw plant oils had considerable advantages over corresponding biodiesel as regards life-cycle energy and greenhouse gas emission analyses. Depending on either primary energy or fossil energy requirements, the life-cycle energy ratio of raw plant oil was in the range of 2–6 times higher than that of biodiesel. Moreover, raw plant oil had the highest potential of reducing life-cycle greenhouse

gas emissions as compared to biodiesel. In addition, biodiesel was formed by the transesterification reaction of triglycerides with alcohols in the presence of a catalyst and produced glycerol as a co-product. Since glycerol was expensive to purify or convert to a value-added product, it caused problems of disposal and environmental concern [25].

The objectives of this study were to prepare rapeseed oil/diesel-ethanol hybrid fuels using the micro-emulsification technique, and to evaluate their relevant properties, engine combustion and exhaust emission characteristics. After describing the methodology for the preparation of the hybrid fuels, the main chemical and physical properties of the fuels were analyzed. The results of the engine combustion and the emission characteristics of a DI diesel engine operated on these hybrid fuels were then reported and analyzed.

2. Material and experimental procedure

2.1. Hybrid fuels preparation

In this study, the diesel fuel, rapeseed oil (RSO), ethanol, and oleic acid used in this study was obtained commercially from a local company and used in the experiments as the blending stock. The diesel fuel used in this experiment was 0# diesel in China. To solve the problem of the high viscosity of vegetable oils, micro-emulsions with solvents such as methanol, ethanol and 1-butanol have been investigated. A micro-emulsion is defined as a colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimension generally in the 1–150 nm range. It has been reported that micro-emulsions are instantaneously formed when all the components are put together in required proportions [26]. The aim of surfactant addition is to reduce oil and water interfacial tension, activate their surfaces and maximize the superficial contact area to make micro-emulsions [27]. The co-surfactant permits to improve the migration of surfactant at oil/water interfaces and enhance the stability of the micro-emulsion [28,29]. The hybrid fuels investigated in this study are micro-emulsions consisting of vegetable oil/diesel blend, ethanol and surfactant mixtures. The rapeseed oil/diesel blend is the based fuel, in which the volume fraction of rapeseed oil is 20% (denoted as DRO20). The surfactant used in this study is oleic acid. This kind of chemical products can be characterized by their hydrophilic-lipophilic-balance (HLB) number. Oleic acid has a HLB number equal to 1.0. This surfactant is more lipophilic than hydrophilic and hence appropriate for making water-in-oil emulsions. In this study, 1-butanol is chosen as co-surfactant because it is entirely miscible with diesel fuel at ambient temperature. 1% aqueous ethanol is used in place of water as the polar liquid phase because it is a renewable fuel that can be obtained by fermenting agricultural waste containing sugar [30]. Table 1 shows the main properties of the blending stocks of hybrid fuels.

In order to study phase behavior and miscibility of the hybrid fuels, the principles of ternary phase diagram representing three-component system were used. A ternary phase diagram is an equilateral triangle which consists of three vertices of three components. The composition at each point in a ternary phase diagram demonstrates the volume percent of the three components (A, B, C) as follows [31]:

$$x\%A + y\%B + z\%C = 100\%$$

Two vertices at the bottom of triangle represent DRO20 and ethanol at the left side and the right side, respectively, while the upper vertex represents the oleic acid/1-butanol mixture. DRO20 and ethanol blends were made where the ethanol component was varied from 0% to 100% by volume in 10% increments. Mixing them

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